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Verification of Correlation of Speed of Sound and QUS Parameters for Infection of Ulcer just under Skin

皮膚下組織の感染に対する音速と QUS パラメータの相関性の検証

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1. Introduction

One of simple and quantitative evaluation candidates for the infection of the issue is tissue characterization based on quantitative ultrasound (QUS) diagnosis. For QUS diagnosis, it is necessary to detect the difference of sound property between non-infected and infected region. We aim to combine the features of the infection under the skin issue with the results of analysis macroscopically. This report focus on the parameters of the statistical models and the correlation of speed of sound (SoS). At first, we indicated 4 QUS parameters based on statistical analysis of echo amplitude envelope and the difference of SoS measured by acoustic microscopy.

2. QUS Parameters Based on Envelope Statistics

The Nakagami distribution (NA) is one of the probability density function (PDF) defined by

$$p(x) = \frac{2m^m x^{2m-1}}{\Gamma(m)\Omega^m} \exp\left(-\frac{x}{\Omega}x^2\right) \qquad (1)$$

where x is the amplitude envelope, m is the shape parameter and Ω is the scale parameter. Shanker proved that the NA distribution could model the conditions of pre-Rayleigh (m < 0.5): low scatter density in the scatter structure, Rayleigh (m = 1): high scatter density, post-Rayleigh (m > 1): high scatter density and SNR [1].

The Weibull distribution (WE) is modeling the amplitude envelope with lower scatter density than the case of PDF obeys to Rayleigh distribution [2]. The WE distribution is defined by

$$p(x) = \frac{\beta}{\alpha^\beta} x^{\beta-1} \exp\left[-\left(\frac{x}{\alpha}\right)^\beta\right] \qquad (2)$$

where α is the scale parameter and β is the shape parameter. The SNR monotonically increases with β, the WE distribution can be used to model pre-Rayleigh ($0 < \beta < 2$), Rayleigh ($\beta = 2$), post-Rayleigh ($\beta > 2$) conditions.

The Generalized Gamma (GG) distribution has three parameters that likely developed to fit the heavy tail of histogram. The GG distribution is defined by

$$p(x) = \frac{cx^{ac-1}}{b^{ac}\,\Gamma(a)} \exp\left[-\left(\frac{x}{b}\right)^c\right] \qquad (3)$$

where a is the shape parameter and c is the shape adjustment parameter. The parameter a drops down toward unity, and c goes up toward unity, as the scatter density [1]. The distribution also includes the character of previously discussed distributions: NA (c = 2) and WE (a = 1).

The privious research conducted a study on the statistics of the envelope of two-demensional high-frquency (i.e., > 15 MHz) ultrasound backscatter signals from human skin. Raju's results indicated that, for example, the WE and GG distribution were capable of modeling the envelope statistics well [3].

3. Materials and Methods

When the tissue under skin have some damage such as ulcer, the tissue will be healing by producing and increasing a granuloma. The main composition of a granuloma is collagen (1 nm ~ 10 μm). In case of developing infection, the necrotic tissues are mixed in addition to produce collagen because of occurring cell necrosis.

Measurement objects were 3 types of ulcer models (non-infection, critical colonization, infection) of rats. The ulcer was caused by cutting off epidermis, dermis and subcutaneous tissue. Non-infection model was heal under the wet condition. In case of critical colonization and infection models, bacteria were implanted on the surface and inside the

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wound, respectively.

A modified ultrasonic diagnosis equipment (Aplio500, Toshiba Medical Systems Co.) and the linear phased array transducers (PLT-704SBT, Toshiba Medical Systems Co.) were used for acquiring the echo data of ulcer skin tissues. The center frequency of trans/receive ultrasound was 8.9 MHz, and the sampling frequency was 40 MHz. The maximum depth was set to 30 mm, and the focus depth was set to 20 mm. Echo amplitude envelope data of each scan line were derived from RF data by applying a Hilbert transform.

A region of interest (ROI) was set manually location including all of the wound just under the skin. In the ROI, an analysis window of 1.1 mm * 4.7 mm (58 pixels in depth * 48 pixels in lateral) was scanned for axially and laterally by shifting each of 4 pixels. The 3 PDFs (NA, WE, GG) distribution were fitting for envelope data in an analysis window.

The measurement of SoS of same tissue from RF data acquisition was also done by a scanning acoustic microscopy (SAM) for understanding the relationship between the acoustical and histological features. Histological sections were prepared as sliced specimen with 10 μm thickness. The SoS was measured by SAM (modified AMS–50SI, Honda Electronics Co. Ltd) and a PVDF TrEE transducer (HTD 100–1215) with center frequency of 100 MHz. After measuring, a pathology specimen (Masson's trichrome stain) was prepared for histology.

4. Results

Figure 1 shows the two dimensional distribution of SoS corresponding the pathological images. The SoS was near under the ulcer in case of non-infection model. However, the SoS was fast on the surface of tissue in case of critical colonization model. Moreover, the SoS was also fast just under the ulcer in case of infection model. It is confirmed the area that has high SoS value is the area of necrotic tissues on the pathological images. It shows that the acoustic property between collagen and necrotic tissue are different due to occur the infection.

Table. I and **Fig. 2** shows the variation coefficient, the average and the standard deviation of

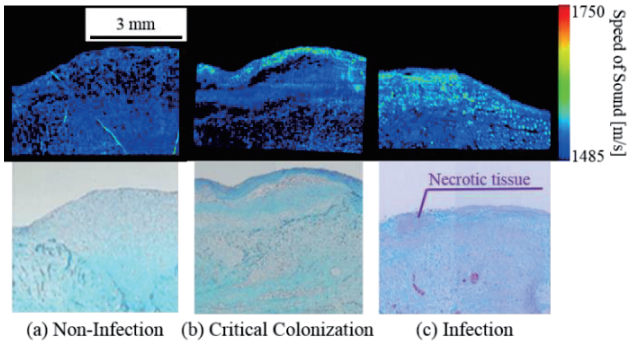

Fig. 1 Distribution of speed of sound and corresponding pathlogical images.

Table. I Variation coefficient [%] of estimated model parameters in case of non-infection (N), critical colonization (C) and infection (I) model.

	N	C	I
WE-β	16.8	21.1	16.1
NA-m	11.0	14.1	10.4
GG-log a	66.0	79.5	91.4
GG-c	38.3	31.2	42.1

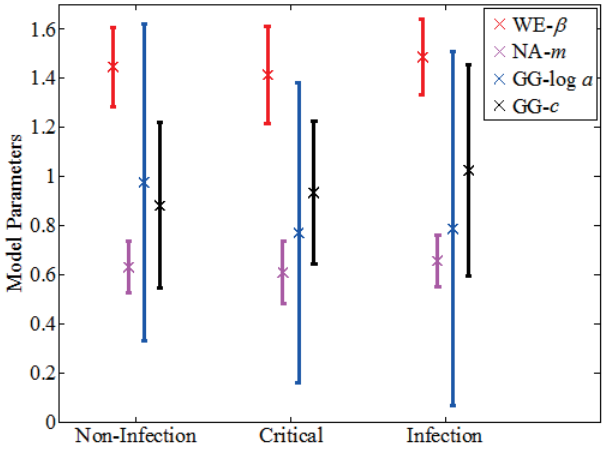

Fig. 2 Average and standard deviation of estimated model parameters.

estimated model parameters, respectively. In all cases of 3 rat models, the average of parameter β and m were low ($\beta < 2$ and $m < 1$). This means that the structure under the ulcer is wholly low scatter density. Moreover, it was difficult to distinguish between collagen and necrotic tissue only to fit the WE and NA distribution because the variation coefficient of β and m was also near for all cases.

Unlike the WE and NA distribution, the parameters of GG distribution varied widely in case of infection model. It is considered that parameter a and c can detect the character of PDFs that can show no difference from β and m.

5. Conclusion

QUS parameters related to scatter density and the SNR were indicated. It is considered the localized structure under the ulcer can be estimated by including other statistical models. In the next step, we verify the correlation of the SoS and some QUS parameters.

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